AD-A086 173 GEORGIA INST OF TECH ATLANTA F/G 17/8
A TRACKING PERFORMANCE STUDY OF LARGE DIMENSIONED TARGET THROUG--ETC(U)
JUN 78 M L MORGILLO DAAG39-77-C-0041
UNCLASSIFIED NL

1 OF 1
ADA
086173

END
DATE
FILMED
8-80
DTIC

PHOTOGRAPH THIS SHEET

ADA086173

DTIC ACCESSION NUMBER

II

LEVEL

INVENTORY

Georgia Inst. of Technology
Atlantia, GA

"A Tracking Performance Study of Large Dimensional Targets Through an Optical Sight"
Master's Thesis

DOCUMENT IDENTIFICATION

Contract No. DAAG39-77-C-0041 June 1978

DISTRIBUTION STATEMENT A
Approved for public release;
Distribution Unlimited

DISTRIBUTION STATEMENT

ACCESSION FOR		
NTIS	GRA&I	☒
DTIC	TAB	☐
UNANNOUNCED		☐
JUSTIFICATION		
BY Per DITC Form 50 on File		
DISTRIBUTION /		
AVAILABILITY CODES		
DIST	AVAIL AND/OR SPECIAL	
A		

DISTRIBUTION STAMP

DTIC
ELECTE
S JUL 1 1980 D
D

DATE ACCESSIONED

80 6 20 001

DATE RECEIVED IN DTIC

PHOTOGRAPH THIS SHEET AND RETURN TO DTIC-DDA-2

DTIC FORM OCT 79 70A

DOCUMENT PROCESSING SHEET

~~A~~ TRACKING PERFORMANCE STUDY OF LARGE DIMENSIONED TARGETS THROUGH AN OPTICAL SIGHT

A THESIS

Presented to

The Faculty of the Division of Graduate Studies

By

Michael Luciano Morgillo

In Partial Fulfillment

of the Requirements for the Degree

Master of Science in Industrial Engineering

Contract No. DAAG39-77-C-0041

Georgia Institute of Technology

June, 1978

(1) A TRACKING PERFORMANCE STUDY OF LARGE
DIMENSIONED TARGETS THROUGH AN OPTICAL SIGHT.

(6) A THESIS

Presented to

The Faculty of the Division of Graduate Studies

By

Michael Luciano Morgillo.

In Partial Fulfillment

of the Requirements for the Degree

Master of Science in Industrial Engineering

(2) Atlanta,

(3) Georgia Inst~~itute~~ of Technology

(5) June, 1978

(12) 67p.

A TRACKING PERFORMANCE STUDY OF LARGE

DIMENSIONED TARGETS THROUGH AN OPTICAL SIGHT

Approved:

Thomas L. Sadosky

Thomas L. Sadosky, Chairman

Russell G. Heikes

Russell G. Heikes

Leslie G. Callahan

Leslie G. Callahan

Date Approved by Chairman 5/12/78

ACKNOWLEDGEMENTS

There are several individuals who, by their assistance or support, contributed considerably to this study. Dr. Thomas L. Sadosky, Chairman of my thesis committee, provided immeasurable guidance and support throughout the project. A special appreciation is also extended to Dr. Leslie G. Callahan and Dr. Russell G. Heikes for their assistance as members of the reading committee.

I would also like to express my appreciation to the United States Army Human Engineering Laboratory, Aberdeen Proving Ground, Maryland. In particular, Mr. Herb Cheever for his assistance with equipment, time, and research material.

TABLE OF CONTENTS

APPENDICES (continued)

LIST OF TABLES

LIST OF ILLUSTRATIONS

SUMMARY

There have been many tracking studies performed throughout the years in laboratories where a subject is required to track a point on some form of visual display. Very few studies have been performed in the field environment with larger than point type targets. The purpose of this study was to determine the magnitude and distribution of error when tracking the unmarked center of mass of a large diameter circular target and eventually to compare these errors to those found in the tracking of a circular target with a marked aim point at the center of mass.

Investigation of the pertinent literature revealed the approaches previously taken, the types of experiments, the generally accepted measures of determining tracking error and the historical results. The literature also clearly pointed out the errors and pitfalls which had been discovered in previous tracking experiments. All this information provided a basis for the experimental design used in this research.

The equipment used for gathering and analyzing the data was of the highest quality and the extensive safeguards utilized were an attempt to reduce experimental error to absolute minimums. The target was circular, and angular velocity was constant.

The statistical measures used to analyze the data were standard deviation of error, standard deviation of error corrected for autocorrelation, mean error, autocorrelation coefficients, range of observations and computer drawn histograms of the data.

The results show that the distribution of error did change as a function of visual angle. As visual angle increased, the distribution of error tended to change from what appeared to be a uniform distribution to a distribution that had the tendency to peak. This was illustrated in the frequency histograms and verified using the aforementioned statistical tools. The standard deviation of tracking error was approximately 57 percent larger using targets without marked aim points compared to targets with marked aim points. There was a slight decrease in standard deviation of error as targets become larger; however, this trend was not considered significant from a practical point of view.

CHAPTER I

INTRODUCTION

Background

Tracking performance studies have been conducted for many years. Most of this work, however, is concerned with the tracking of point targets on some form of visual display. Almost no work has been done outside the military community on the tracking of large dimensions targets.

Initial work in this area was performed after World War II by the U.S. Air Force. Some follow-up work was accomplished by the U.S. Army and both services tentatively agreed that distribution of tracking error was in the form of the bivariate normal distribution. A large dormant period ensued and it was not until the advent and wide usage of wire-guided, line of sight missile systems that the question of distribution of tracking error arose again. Scanty field data on tracking, psychological reports on vision and acquisition, and laboratory work on learning all indicated that the distribution of tracking error might be other than the classical assumption of normal.

Problem Definition

The purpose of the study was to determine the magnitude and distribution of error when tracking the unmarked center of mass of a large diameter circular target and eventually to compare these errors to those found in the tracking of a circular target with a marked aim point at the center of mass.

Scope

The approach to the problem was a search of existing literature to ascertain what work had been accomplished on the subject. Once this had been done, a field experiment, using six subjects, was conducted. A circular target was used and target visual angles between 20 and 200 minutes of arc were investigated.

Summary of Methodology

The experiment was conducted on a field with clear visibility to a maximum range of 200 meters. Each of the six subjects undertook a standardized training program prior to initiation of the experiment. The subjects were required to track through a rifle scope a circular target moving at the constant angular velocity of 11 milliradians per second. The scope was mounted on a movie camera affixed to a viscous damped tripod. Each subject performed the tracking task at various rifle scope magnifications to produce different apparent target sizes.[1] Their deviations, from center of mass, were measured by analysis of the movie film using a motion analyzer. Several measures of tracking performance were used. The first was a frequency histogram showing a pure distiribution of error in target inches from the actual center of mass of the target. Next, standard deviation of error and mean tracking error as a function of visual angle were measured. To account for

---

[1] The apparent size of a target is a function of actual target size, range, and magnification of the scope.

any time series correlations within the trials, auto correlation coefficients were calculated and the standard deviation of error adjusted. Finally, a plot of the range of values for each subject's trial and the auto correlation coefficient at each trial were plotted as a function of visual angle.

CHAPTER II

LITERATURE REVIEW

General

The modeling of human performance in tracking tasks has been studied intensely. Numerous mathematical models and computer simulations have been constructed to mimic various forms of tracking tasks in order to predict how a human will perform when interfaced with the actual system. Most of these endeavors, however, were concerned with correlating a small or single point target with a single point or small cursor response. Error, in general, was judged as a function of time on target, a correct response, or time not on target, an incorrect response. Very little work in the field has been performed dealing with the tracking of large dimensioned targets. Error with this type target may be measured in terms of time on or off target, time on or off an aiming point or a functional relationship associated with range.

Approach to Tracking Problems

Humans are what may be described as an "adaptive" element in a manual control system. This means that their response to a stimulus will vary from situation to situation and from person to person. In a tracking task, the subject will attempt to optimize his performance by integrating all available system outputs and responding with an appropriate output pattern. The amount, type, and form of information presented to the subject will guide him in the direction of optimal performance.

There are two basic types of tracking systems. The first of these is titled pursuit tracking (Figure 2-1). This entails a situation where the target motion and the response are viewed separately and independently on a single display. The subject attempts to align his response to that of the target position and error is measured by the difference between the two. The second type of tracking system is known as compensatory tracking (Figure 2-2). In this form, there is a fixed element on the display. A second, moving element, is also displayed and this represents the subject's manual cue to the tracking error. Error here is shown as the difference from the fixed reference point to the position location of the response element. In this way, the subject sees only error. The basic advantage of the pursuit system is that it displays both target and response location while the compensatory type exhibits only tracking error. Senders and Cruzen, in 1952, demonstrated that performance is generally better with pursuit tracking.

A third type of tracking situation is encountered when dealing with visual search and recognition. This is referred to as a predictive or preview tracking system (Figure 2-3). This may incorporate pursuit or compensatory characteristics. In predictive tracking, some advance knowledge of system behavior is presented. Wierwille, in 1964,demonstrated a 25% reduction in tracking error using predictive tracking. Many real world situations entail predictive tracking. The most common example would be driving an automobile on a flat, winding road. The driver can see each curve as it approaches and make preparations for controlling the automobile before reaching the curve.

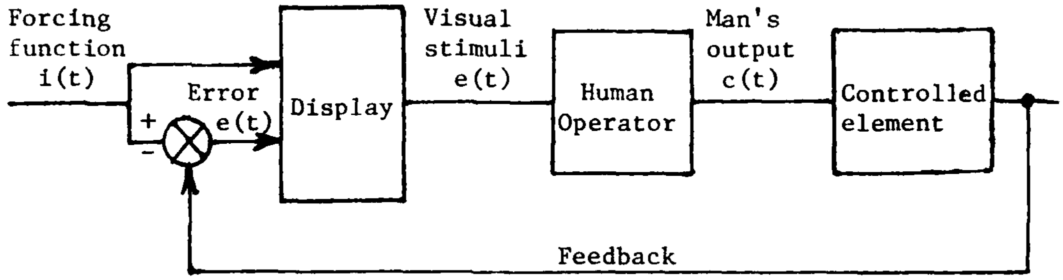


Figure 2-1. Block Diagram of Pursuit Tracking

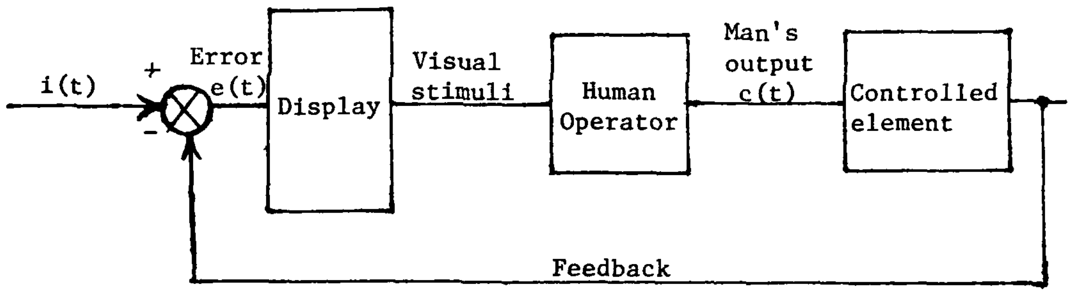


Figure 2-2. Block Diagram of Compensatory Tracking

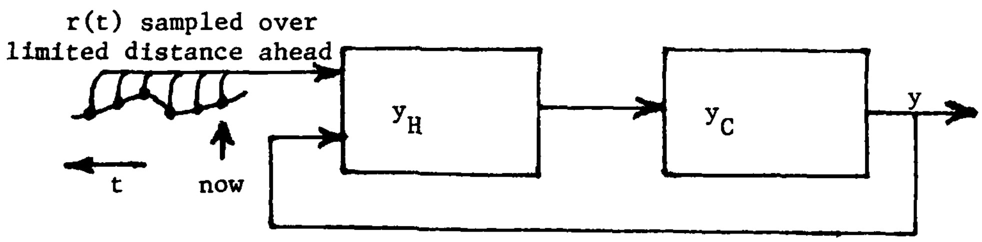


Figure 2-3. Block Diagram of Preview Tracking

Classes of Variables

In any manual control system, the operator's performance will depend on a number of variables associated with the particular situation. These variables may be divided into four major categories. The first of these categories contains variables which are task related. Task variables include such things as the type of information and manner of display, system dynamics, and the type and position of controls. These variables are altered with the physical system itself. The operator works only in task variables.

Environmental variables, the second category, include such factors as illumination, temperature, vibration, additional tasks and other general working conditions. Under laboratory conditions, most environmental variables can be held constant.

The next category is associated with what is called operator-centered variables. This class includes all the non-tangible factors such as motivation, training, and skill. It also includes both physical and mental fatigue.

The final set of variables, known as procedural variables, include instructions given to perform the task, design or measurement of performance and the resources of time and effort used.

Tracking Experiments

Tracking experiments can be performed under both laboratory and field conditions. The typical laboratory experiment involves a subject attempting to track a target projected on a CRT display. In contrast, the field experiment attempts to simulate real conditions by allowing the subject to track using operational tracking apparatus, for example, an anti-tank weapons system, modified for data collection.

The general laboratory experiment contains a display, usually visual, an operator, a control level, and a control element. The control lever transforms the operator's correction signal to a machine signal; the control element sums the dynamics of the external elements and makes the appropriate correction which is then fed to the display. Early experiments required operators to correlate a reference cursor on a CRT display to a spot driven by a random signal generator. The operator controls the cursor by a hand control commonly referred to as a joy stick. Different factors can be tested by entering varied parameters into the system. For example, target size has been simulated by making images unclear and their center of mass indiscernible.

Two types of performance measures are normally used in laboratory experiments. The first of these is root mean square error. Some form of electrical device continuously obtains the magnitude of error (an electric voltage), squares this voltage and integrates it over the period of the trial. This voltage can be displayed on a voltmeter or recorded on paper using a printer. The square root of this value produces the index of error. This voltage must be computed with respect to an absolute reference of zero volts, in order to eliminate any bias in the sytem. As a result, the RMS error provides both the variability of the operator's distribution of amplitudes and any constant error in average cursor position.

The second performance measure is time on target. This might be employed when a larger than point type target is used and discrete target zones are being investigated. It has been demonstrated that time on target scores are nonlinear and are relatively insensitive to small changes in human performance; so therefore, this method is generally not recommended.

The field experiment is a more realistic means of gathering tracking data, but the controls available in a laboratory arrangement are sacrificed. This type of experimentation is normally performed when information about a particular piece of hardware is desired. The most appropriate example of this might be the performance testing of a military anti-tank weapons system. The actual system could be modified to carry a laser, rather than a live missile, and its operation evaluated under realistic conditions.

In the field, performance of the operator is normally measured by deviation from either a marked or perceived aim point. The error can be extracted from visual recordings of the experiment continuously or at discrete points in time. From this information, system parameters and tracking performance can be evaluated in a much more realistic manner than in a laboratory arrangement.

Distribution of Error

The classic assumption that distribution of tracking error follows a bivariate normal distribution, had its start in military weapons firing tables. Modes of hit probability for a tank gunner, for example, were based on a normal distribution of error. This assumption has considerable intuitive appeal, but the first empirical study to validate its authenticity was not published until 1955 [Fitts, Bennett, Bahrick, 1955].

Fitts, Bennett and Bahrick presented their study at the 1955 Symposium on Air Force Human Engineering, Personnel, and Training Research, which used autocorrelation and cross-correlation analysis to study tracking behavior. Relying on data gathered for a Ph.D. dissertation at Ohio State, the researchers, as one of their objectives, attempted to determine the distribution of tracking error. The experiment consisted of 50 male and 50 female subjects who were required to track a 10 cpm sinusoidal motion of a line on a CRT display over 14 trials each. The target line remained stationary in the center of the display and the cursor could be moved right or left depending on the motion. A block diagram of the experiment is illustrated in Figure 2-4. This compensatory tracking task was measured both by RMS and time on target error scoring. Three zones of error

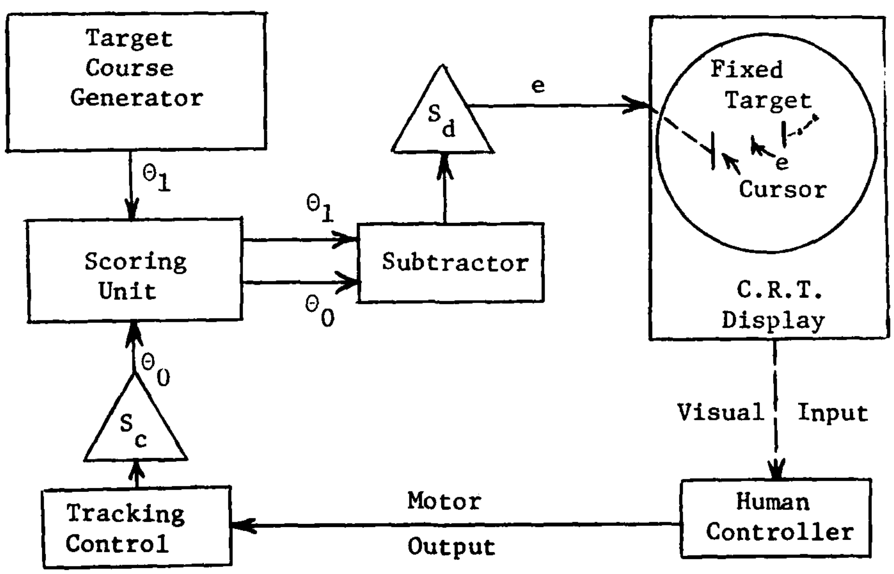


Figure 2-4. Block Diagram of the OSU Electronic Pursuit Apparatus, Adjusted to Provide a Compensatory Display (ref. [9], Fitts, Bennett, Bahrick)

corresponding to .1, .3, and .6 inches of displacement on either side of the cursor were considered. The RMS and time on target scores were plotted and compared to scores which were predicted, assuming the normality assumption. This is shown in Figure 2-5. They concluded that the empirical curves corresponded "moderately well" to the normality assumption.

Next, considering the learning aspect, the researchers plotted the error amplitude of the second, sixth and fourteenth trials of the subjects. These distributions were plotted against normal curves with the same mean and standard deviation as that of the test data, and these results are shown in Figure 2-6. Finally, they took the error amplitude distribution of the 50 male subjects, who were determined to be better trackers than the women, converted their raw scores to standard normal and plotted them against the corresponding normal curve. This is shown in Figure 2-7. (These graphs did not appear in their entirety in the paper, but were published later.) Their findings were that "after some practice in tracking coherent targets, the error records of individual subjects tend to have a normal or nearly normal amplitude distribution. . . The correlations among error RMS scores and various time on target scores follow a pattern that would be predicted on the assumption that all scores are samples from a process that has a normal amplitude distribution.[2]

Bahrick, Fitts and Briggs in 1957 reinforced the early work in an article dealing with learning curves. Using the same data, they

---

[2] Fitts, Bennett, Bahrick, p.40

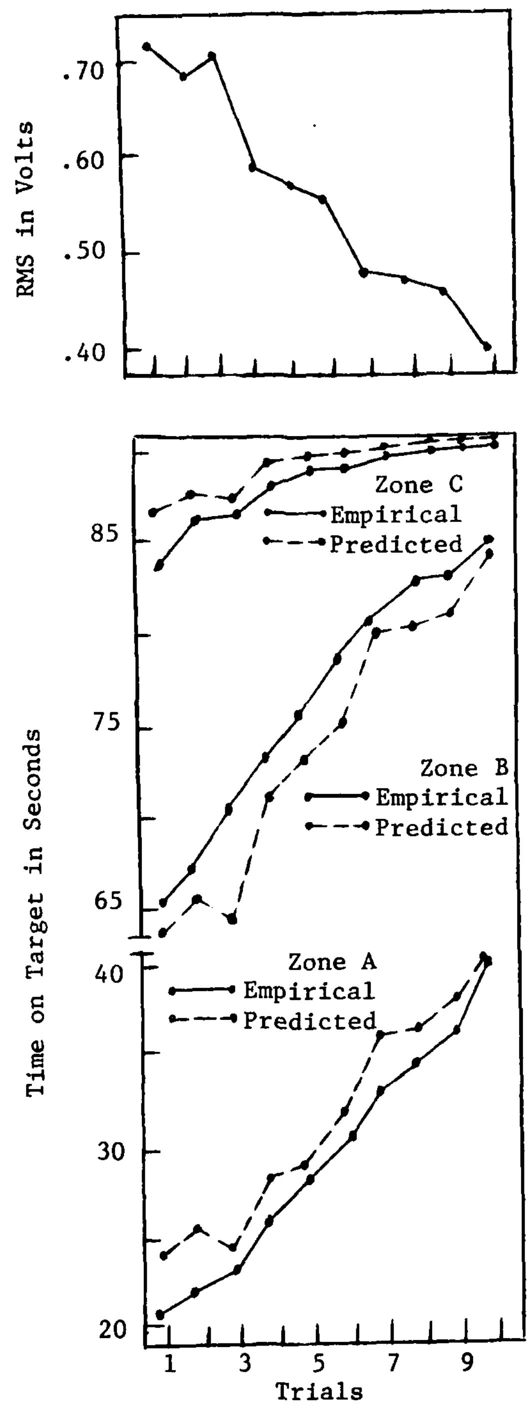


Figure 2-5. Time-On-Target and RMS Scores of 25 Male Ss on a Simple Tracking Task

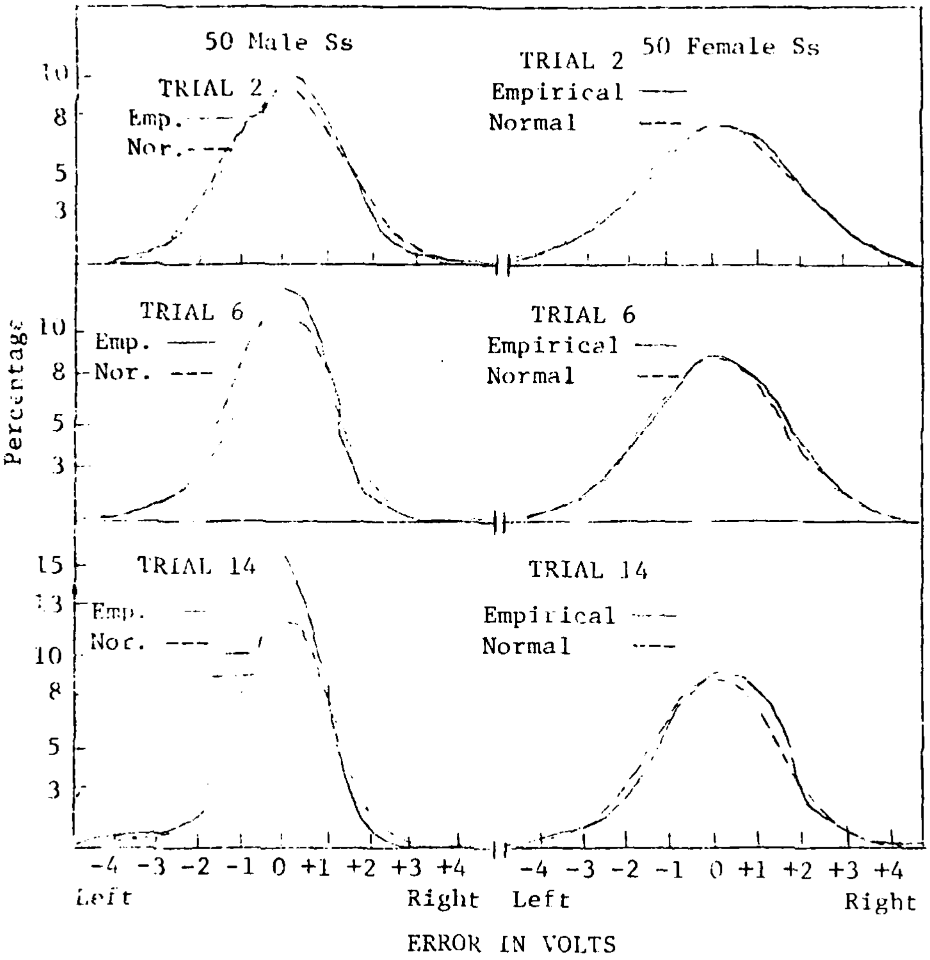


Figure 2-6. Empirical Distribution of Error Amplitudes at Three Stages of Training

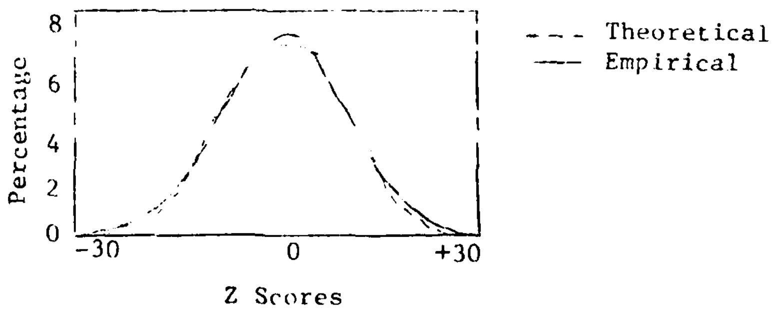


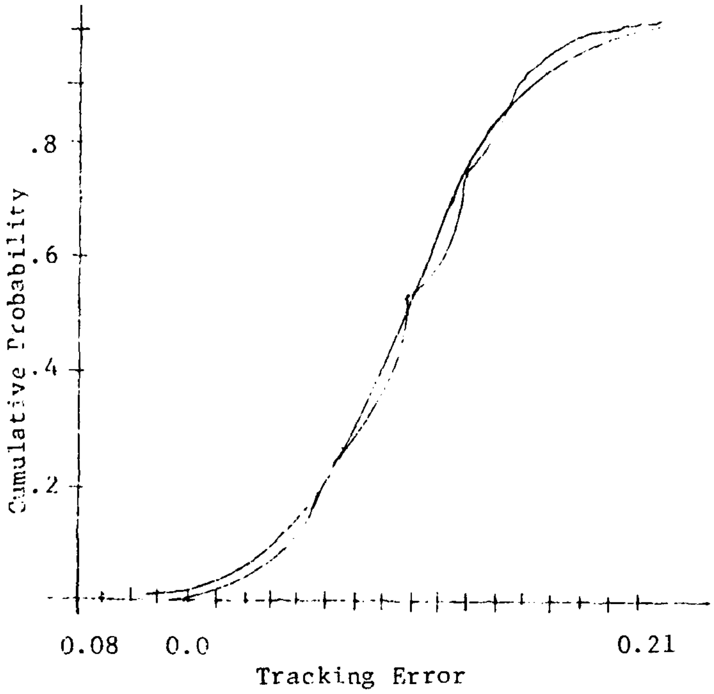
Figure 2-7. Error Amplitude Distribution for Male Ss on Trial 14, After Conversion into Z Scores

attempted to explain why deviations from normal were obtained in the experimental work. They concluded that "the peaking is not due to departures from normality in the error amplitude distributions of individual subjects, but rather that it is due to the combining of normal distributions which among themselves are not normally distributed."[3] Again, emphasis was placed on the normality assumption holding true for trained trackers. This was not, however, substantiated with more than conjecture.

In early 1977, a field test of the normality assumption was performed. The Systems Performance and Concepts Directorate of the U.S. Army Human Engineering Laboratory (HEL) analyzed field test data for trained trackers to determine the validity of the normality assumption. Using a laser designator, subjects tracked both front and side views of a tank silhouette, with and without a marked aim point. Targets were tracked at ranges of .96 km. and 2.01 km. The researchers chose to plot a predicted distribution, using the normal assumption, and the actual cumulative probabilities, versus the tracking error. This was accomplished by a calculator plotter specially programmed by HEL. A typical graph of their results is shown at the top of Figure 2-8, with the worst case at the bottom. From observation, HEL concluded that human tracking error follows a bivariate normal distribution.

Recently, another distribution of error has been theorized to occur when subjects track a large moving target. Mr. Floyd Hill of the U.S. Army Organizational Testing and Evaluation Agency (OTEA) has

[3]"Learning Curves, Arts or Artifacts." Psychological Bulletin, Vol. 54, No. 3, 1957, p. 263.



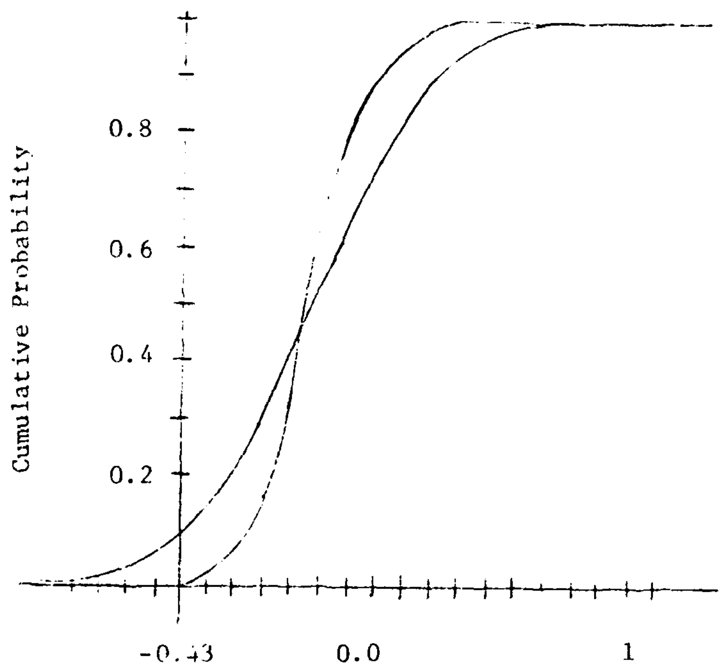


Figure 2-8. Typical Error Distribution, HEL Field Test, 1977

suggested that when a subject is tracking a large target, for example, a tank, he is not necessarily attempting to track center of mass of the target, but is simply trying to keep his cursor within the boundary of the target. This will not lead to a normal distribution of error, but to a bimodal distribution with corrections made only when the subject strays toward the edges of a target.

There is intuitive appeal for the theory that the edges of the target play a more important role in tracking than an unmarked center of mass. It is a well known axiom in psychology that when an individual looks at an object his eyes tend to fixate at the more pronounced edges of the object. Although laboratory experiments on large and narrow targets show a strong correlation to the distributions of error of point targets, it appears that no field experiment has been performed on large targets at a range less than .96 km. and no functional relationship has been developed between magnitude of tracking error and its distribution as a function of apparent target size.

Human Error in Tracking

There are factors which affect the performance of an individual in a tracking task. Most of these are physiological and are more pronounced in some individuals than others.

A major source of physiological error is body tremor. This may be defined as an involuntary shaking or trembling of voluntary muscles of the body or parts of the body. It may be the result of physiological, emotional or environmental conditions. Compounding any tremor error is the small amount of mass inertia found in virtually all types of control mechanisms.

To eliminate this problem from an optical control task and allow the physical movement of the control mechanism to be smooth, it has been determined that a viscous-damped resistance system should be incorporated into the control loop.[4] The viscous-damped resistance system has several major operational characteristics which make it useful. First, its resistance is directly proportional with the control velocity placed on the control, but is independent of acceleration and displacement. Second, it eliminates tremor because it resists any quick movement. Finally, it reduces the chance of undesired activation and aids the operator in making smooth, controlled movements. With the aid of this apparatus, body tremor can be reduced to a negligible factor in the control experiment.

Another source of error divorced from the tracking task itself is the movement and fixations of the eye. First, the eye does not continuously monitor an object, but takes samples of it at an extremely high rate of speed. To take these samples, the eye is capable of making many discrete movements each second. Ratliff and Riggs, in 1950, reported three readily distinguishable types of eye movements: 1) high frequency tremor of 30 to 70 cps. with low amplitude of 15 to 20 seconds or arc; 2) slow drifts lasting up to 10 seconds with amplitude up to five minutes of arc; and 3)saccades or very rapid flicks occurring at irregular intervals with a mean of six minutes of arc. In 1956,

---

[4] Other resistance devices are available for different control mechanisms.

Cornsweet demonstrated that in individuals with normal, healthy eyes, the first two types of eye movement have no effect on stability of the visual world and cannot be controlled. Saccadic motion is, however, under visual control and serves to realign the eye on its fixation point.

To understand this concept more easily, a geometric interpretation is presented. Figure 2-9 represents a schematic drawing of the eye. The visual axis is a line drawn through the center of the lens and retina. Θ is the off axis angle and is one-half the visual angle. The visual angle is the angle subtended by the eye to encompass an object. The retina initially processes the visual information and transmits it to the brain by the optic nerve.

Saccadic movement of the eye occurs one to ten times per second, but averages about three per second. Between the saccades, the eye fixates on individual areas. This time period is called a glimpse interval, and its reciprocal is known as the glimpse rate. Movement of the eye is necessary because only a small region around the fixation point is clear to the eye. The fovea, located in the center of the retina, is the only portion of the eye which has receptor cells packed closely enough together to make clear resolution possible. The area around the fixation point will therefore be hazy. Eye movement is thus necessary to provide a clear image to the brain.

Considerable research has been performed on eye movements and their effects on tracking, visual acuity and recognition. Authors still debate the importance of the relationship of eye movements and visual tracking. For the purpose of this research, saccadic movement

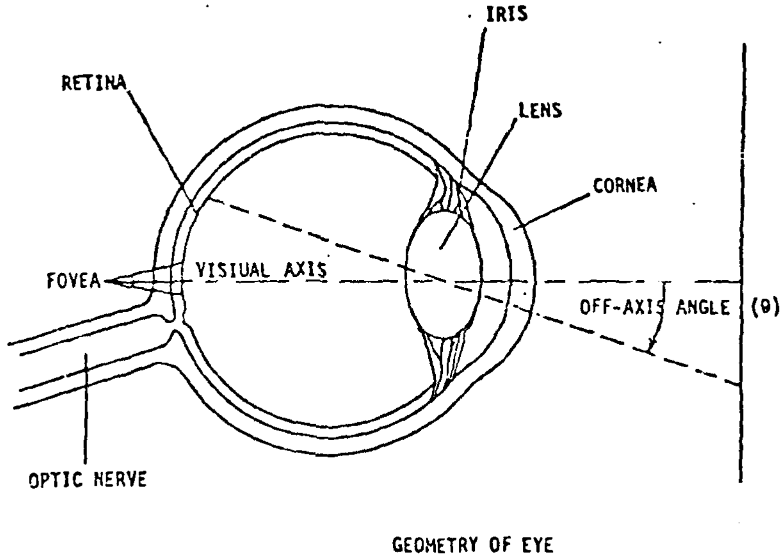


Figure 2-9. Effects of Visual Acuity on Target Acquisition (Ref. [13], Laskin)

will be considered negligible based on the following facts. First, after recognition, visual perception of the target is directly comparable to looking at a picture. Short term memory and awareness of surroundings project the entire target clearly to the brain, even though much of the target might lie in the hazy peripheral vision rangers.[5] Second, while tracking, movement of the eye is at a minimum and saccades should average only approximately one per second.

A final point of error inherent with the eye might be considered to be the blink rate. It has been demonstrated by Lawson in 1948 and by others that there is no degradation in tracking performance after an intentional or unintentional blink. It has also been demonstrated that the blink rate is reduced from 18 per minute at rest (depending on the target resolution difficulty) to as few as three per minute.

Other factors which contribute to non-tracking human error are fatigue, stress, and accuracy vs. time. For each of these items there is no good analytic technique for predicting their effect on the tracking task. Specific tables have been developed for certain tasks, but no general data is available. Because of the wide variety of human behavior and precise system characteristics, only by experimentation or simulation can these factors be properly evaluated.

---

[5] J. D. Gould, "Looking at Pictures," Eye Movement and Psychological Processes, edited by Richard A. Menty and John W. Senders. Hillsdale, New Jersey: Lawrence Erlbaum Associates, 1976, p. 333.

CHAPTER III

METHODS AND PROCEDURES

General

The objective of this study was twofold. The first objective was to determine the distribution of tracking error at various apparent target sizes and the shape of the tracking error distribution. The second criterion was to determine the relationship between standard deviation of error and target visual angle. As already stated, visual angle is the angle subtended at the eye when viewing an object. It is therefore a function of both target size and distance.

The tracking performance of six trained subjects was used. The subjects were trained by repeated practice over 60 trial runs and learning curves were calculated. This work was accomplished in conjunction with this research, but it will not be presented here.

Equipment

The equipment used in this study was developed by the U.S. Army Human Engineering Laboratory (HEL) at Aberdeen Proving Ground, Maryland. It consisted of a variable power rifle scope (2.5x to 8x) with an extended eye piece. It was affixed by way of a slide mount to a 16 mm. Milligan movie camera. The camera was equipped with a six inch lens and was set to film at a rate of four frames per second. The major advantage of the Milligan brand camera was that a frame of film was held firmly in the shutter when it was being exposed, and therefore, no error could be artificially induced by film flutter.

The camera was secured to a limited production HEL general purpose viscous-damped tripod by way of a mounting bracket expressly designed to minimize tolerance errors.

The experimental tripod with its traversing unit weighed approximately 12 pounds. It was designed to be used with loads in the range of five to 32 pounds. (A typical military load for this tripod may be a lightweight missile launcher.) The eye height relative to ground level was adjustable from 22 to 26 inches depending upon the load. In this experiment it was set at 22 inches. The traversing unit encompassed a twofold damping system. In the elevation axis, the damping system had a vane type rotor. In the azimuth axis, the system was drum type. System damping characteristics were determined in a laboratory test; the results are located in Appendix A. The entire system is shown assembled in Figure 3-1.

Test Design

The test was designed to encompass visual angles ranging from 20 to 200 minutes of arc, to simulate a tank-size target from ranges of approximately 100 to 3000 meters.

The test condition consisted of a target propelled in the horizontal plane at a constant velocity. Target sizes of one meter and one half meter diameters were used. Two ranges were also used — 100 meters and 200 meters. By varying the power of the scope in conjunction with the two target sizes and two ranges, the desired

Figure 3-1. Tracking Station Assembly

target visual angles could be achieved (Table 3-1). The targets were flat black in color and were mounted on a 5' x 8' white target board which was mounted to a vehicle with mounting brackets and tie downs (Figure 3-2). In an attempt to keep the distance to the tracking station as constant as possible, the target was moved along a relatively flat horizontal, arc shaped path.

After sixty preliminary runs, the subjects were considered trained. Each subject was required to assume a sitting position at the tracking station (Figure 3-3). A set of pre-printed instructions was read to each subject before the initiation of the experiment (Appendix B). This was done to ensure that all subjects were given identical instructions. Before each individual trial, the subjects were told to lay the rifle cross-hairs on the marked center of the target. A few seconds of film were shot, the mark was removed, and the experimental run was begun. This stationary tracking provided a zero reference point for data reduction and served to eliminate parallax error between the scope and the camera. Additionally, it later served as a medium for determination of experimental human error in data reduction.

Activation of the camera was controlled not by the subject, but by the experimentor who was stationed with the subject at the tracking station. By this method, the subject was not required to concern himself with anything beyond the tracking task.

After initiation of target movement, the target maintained a constant velocity for approximately 45 seconds. To ensure the consistency of velocity, time stakes were positioned along the route and the

Table 3-1. Experimental Conditions

Range (meters)	Target Size (m)	Scope Power	Visual Angle (min of arc)	Condition
200	½	25x	21.48	1
200	½	4x	34.38	2
200	1	2.5x	42.97	3
200	1	3x	51.57	4
200	1	4x	68.76	5
200	1	5x	85.95	6
200	1	6x	103.14	7
200	1	7x	120.33	8
200	1	8x	137.52	9
100	1	4.5x	154.71	10
100	1	5x	171.90	11
100	1	6x	206.28	12

Velocity was 5 mph. or 11 milliradians per second at 200 meters and 2.5 mph. at 100 meters.

$$\text{Visual Angle min. of arc} = \frac{(53.7)(60)L}{D}$$

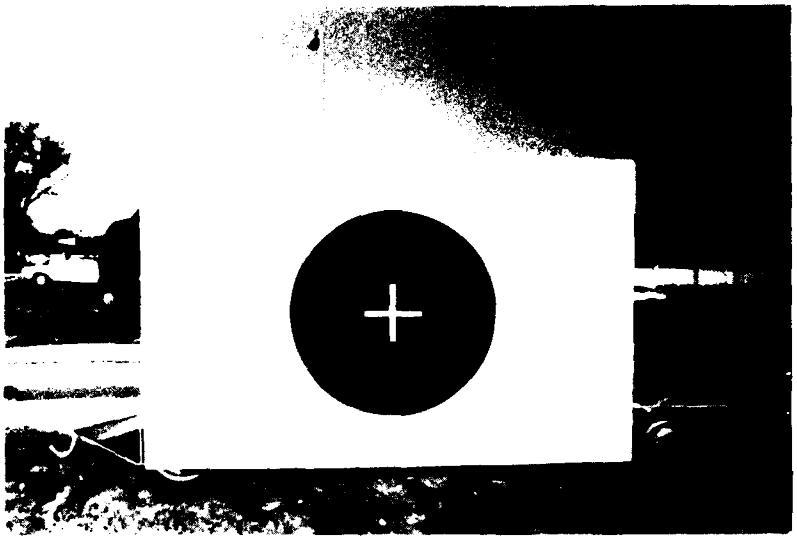


Figure 3-2. Target (with marked center used for zero)

Figure 3-3. Subject and Controller at Tracking Station

vehicle driver maintained a stop watch count in order to pass the stakes at predetermined intervals. The velocity at 200 meters was five miles per hour, and at 100 meters was $2\frac{1}{2}$ miles per hour. The first five seconds of tracking were devoted to acceleration and initial dispacement of the camera, and were not analyzed. Once the tracking began, the subject attempted to track what he perceived to be the center of mass of the target. The test design was blocked, as denoted in Table 3-2, to avoid any possible response patterns and balance any additional learning effects.

It should be noted that the experiment was performed outdoors at an unprotected location. The tracker was therefore subjected to the same environmental conditions, such as wind, which would be encountered during the firing of a light weapons system. Experimentation was terminated, however, when strong wind gusts or rain developed.

Table 3-2. Experimental Design

CONDITIONS #

Subject	1	2	3	4	5	6	7	8	9	10	11	12
1	1	2	3	4	5	6	7	8	9	10	11	12
2	11	12	1	2	3	4	5	6	7	8	9	10
3	9	10	11	12	1	2	3	4	5	6	7	8
4	7	8	9	10	11	12	1	2	3	4	5	6
5	5	6	7	8	9	10	11	12	1	2	3	4
6	3	4	5	6	7	8	9	10	11	12	1	2

(The chart illustrates the order of conditions for each subject.)

CHAPTER IV

EXPERIMENTAL RESULTS

The motion picture film shot in the experiment was taken to the U.S. Army's Human Engineering Laboratory at Aberdeen Proving Ground, Aberdeen, Maryland. There the film was analyzed frame by frame on a specially designed motion analyzer.

The analyzer was designed so that each frame of film was projected, from the rear, onto a translucent piece of plexiglass. A cursor attached to the analyzer was movable over the entire face of the plexiglass surface. By selecting a zero point on the projected film and depressing the set switch on the analyzer, the coordinates in the horizontal (X) and vertical (Y) planes were set to zero. Movement away from this point was measured in hundredths of inches, making it possible for small movements of the cursor to change the coordinates, and therefore, increasing the accuracy of the analyzing procedure. The motion analyzer was electrically connected to a computer terminal, which made a permanent record of each point on punch tape, as well as printing the value on roll paper.

For the purpose of this experiment, the zero point was chosen to be the upper right corner of the target board. This point was selected because the target center was unmarked and because the corner was always very pronounced. A single frame advance on the control panel made the process fairly simple and relatively rapid. A frame of film could be analyzed and recorded in approximately five seconds. As a minimum, 53 frames of film per trial were analyzed for each run[6]

A measure of human error for the data analyzing process was obtained by recording any apparent change in the zero points over a few frames of film during the initial stationary tracking phase for each run of each subject. This was accomplished on the motion analyzer where the zero point should not change from run to run. Any apparent change is human error. (A portion of this could also be attributed to the subject who possibly was not positioned exactly on center, and the rest to the analyzing process.) These changes were summed and averaged, and the error was determined to be less than one tenth inch of actual target inches. Since typical standard deviations in the tracking experiment were in the range of 1.4 to 6.4 target inches, analytic error was considered correspondingly small.

The punch tapes were initially analyzed using a Hewlett Packard mini-computer at HEL. The computer was programmed to convert analyzer inches to actual target inches. The computer also calculated raw mean and standard deviation scores and plotted the points on bar graphs. These graphs were quite helpful in screening the data for "outliers," or points which appeared inconsistent with the bulk of the data.

At Georgia Tech, the data on the punch tape was transferred to magnetic tape and placed in the memory of the CDC Cyber 74 computer.

---

[6] A minimum of 50 observations are required to estimate σ to I $\pm$ 15% with 90% confidence. Chart IX, page 277, Statistics Manual, Crow, Davis, Maxfiled Pub. Inc., New York, 1960.

Next, the analyzer units were again converted to actual target inches and each trial was labeled by subject and run number. Finally, a selective screening of the raw data began.

Each bar graph was first examined heuristically for outliers, which were deleted from the raw data. (This was facilitated by the use of a CRT computer terminal.) Of the 72 total trials, 18 required no editing; the remaining trials averaged approximately 48 out of 53 total observations each after the editing process. The data was then ready to be placed in a series of three computer programs.

The first program determined the range of error for each trial and plotted the data on a seven-interval frequency histogram. This program also determined the mean and standard deviation of the data set. Separate histograms were plotted for the horizontal and vertical planes.

The distributions of the histograms varied widely from subject to subject. A trend, however, did develop. In the horizontal plane for small visual angles, the distributions were fairly uniform. As the visual angle increased, the distributions became more unimodal, with high center peaks. In the vertical plane, the distributions displayed an overall peaking throughout all the runs. This result was expected, since the course was fairly level and few corrections in that direction were necessary. A representative sample of these histograms is found in Figures 4-1 through 4-3.

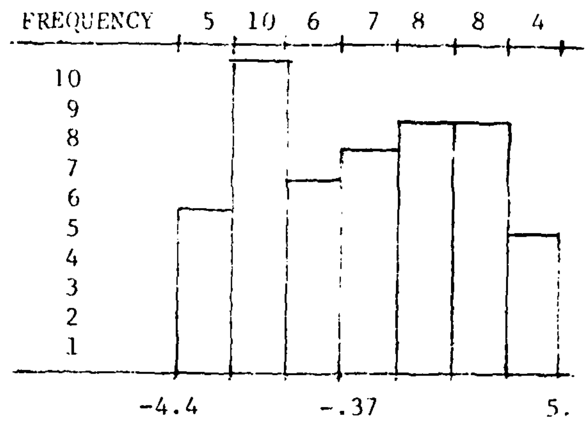
The means and standard deviations for each subject at the various individual target visual angles were averaged, converted to radians, to eliminate the range factor, and plotted. The standard deviation from the final runs in the learning trials using a marked point is also shown. This data is presented in Figures 4-4 and 4-5, and the statistics are found in Appendix C.

The magnitude of sample range in each of the frequency histograms was the next measure of analysis. The range values were averaged across subjects at each visual angle and converted to radians. Again, the average final run from the learning trials is shown. Figure 4-6 is a graphical representation of this analysis; the calculations are found in Appendix D.

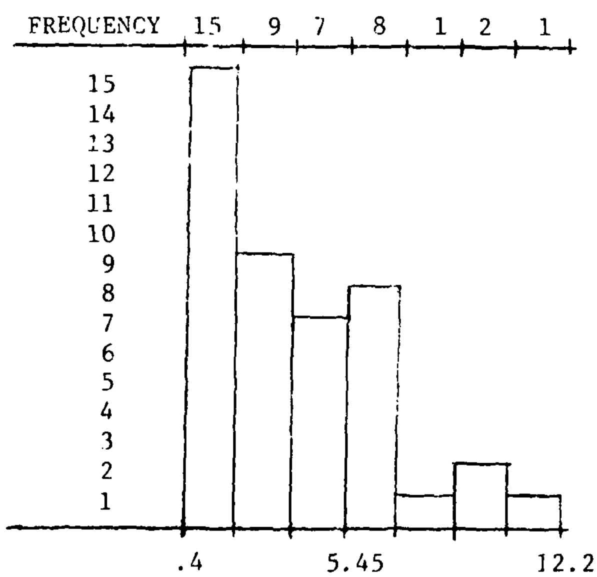
The final area of data analysis concerned autocorrelation coefficients. In a tracking task, each individual observation will have some dependency on the previous observation; this is true for most time series data. The tracker will attempt to correct his tracking at time t dependent on his location at time t-1.

Several test runs were made in order to determine the correct autoregressive process for the experimental data. Lag coefficients (correlation coefficients) were calculated for Lag 1 (t x t-1) through Lag 3 (t x t-3). The samples demonstrated an exponential decay (Appendix E). Discovery of this fact led to the adoption of the first order autoregressive process (AR(1)). An explanation of the AR(1) model used is found in Appendix F. The output of this model yielded a standard deviation exclusive for the autocorrelation factor. A graph of these results and the averaged learning task point is shown in Figure 4-7, and the calculations are found in Appendix G.

A final analysis of the data was performed using autocorrelation coefficients. These coefficients were calculated for each subject and



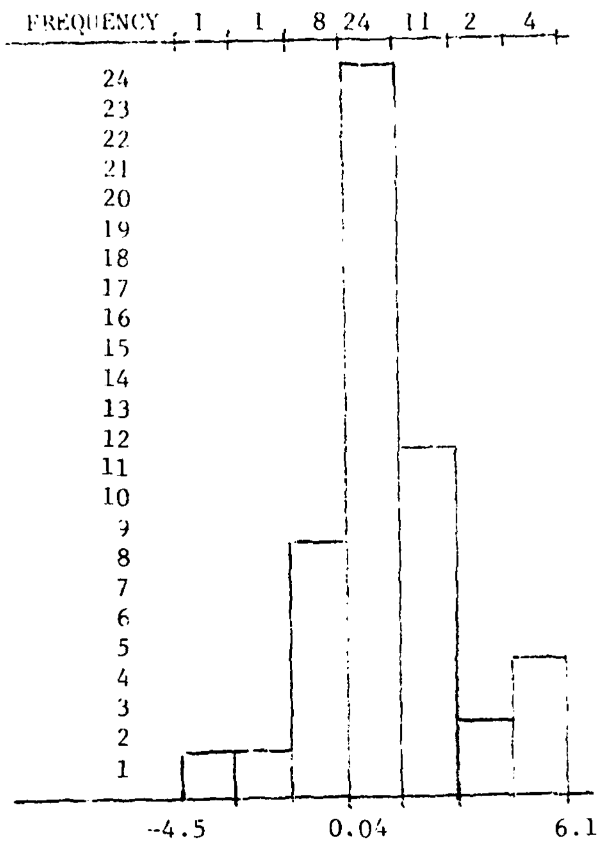
Horizontal Plane



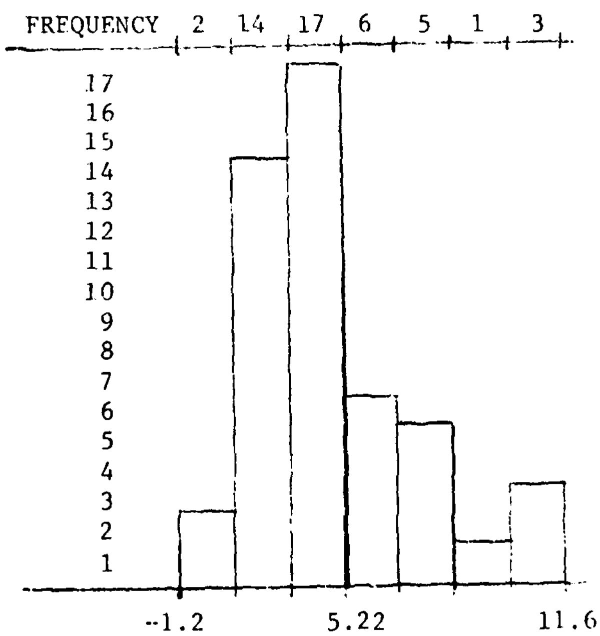
Vertical Plane

Figure 4-1. Typical Error Histogram

(condition 1. 21.48 min of arc)

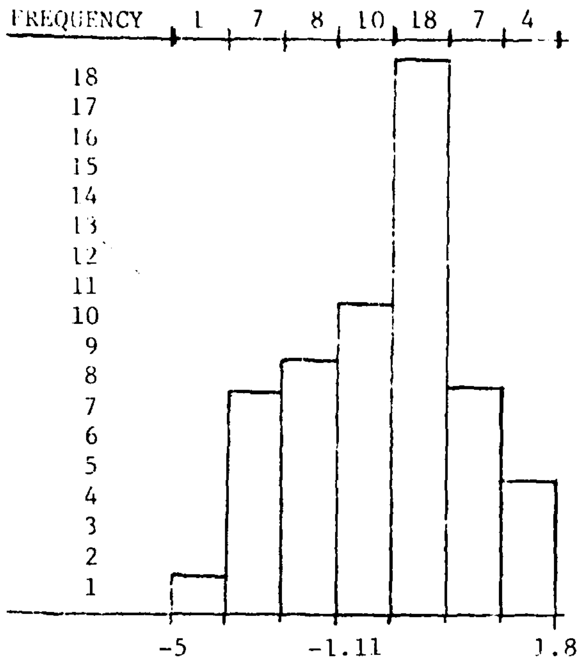


Horizontal Plane

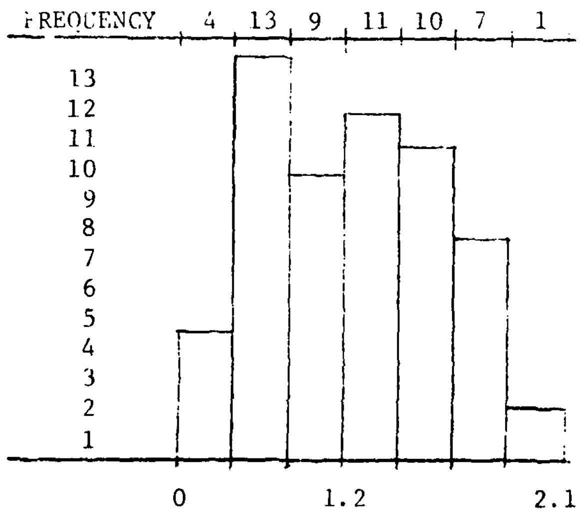


Vertical Plane

Figure 4-2
(condition 7 103.14 min of Arc)

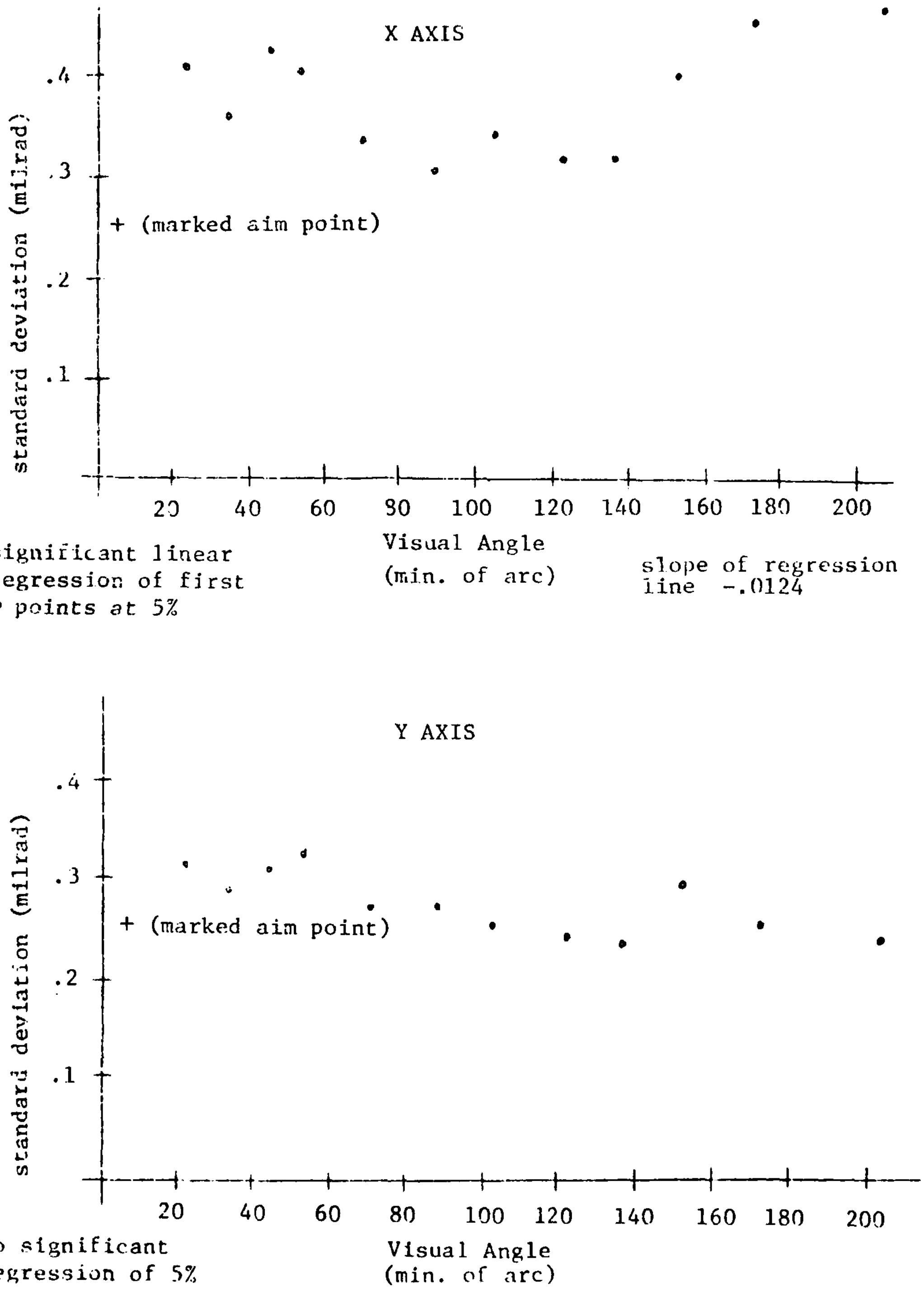


Horizontal Plane



Vertical Plane

Figure 4-3
(Condition 11 171.9 Min of Arc)



significant linear regression of first 9 points at 5%

slope of regression line -.0124

no significant regression of 5%

Figure 4-4. Standard Deviation of Error

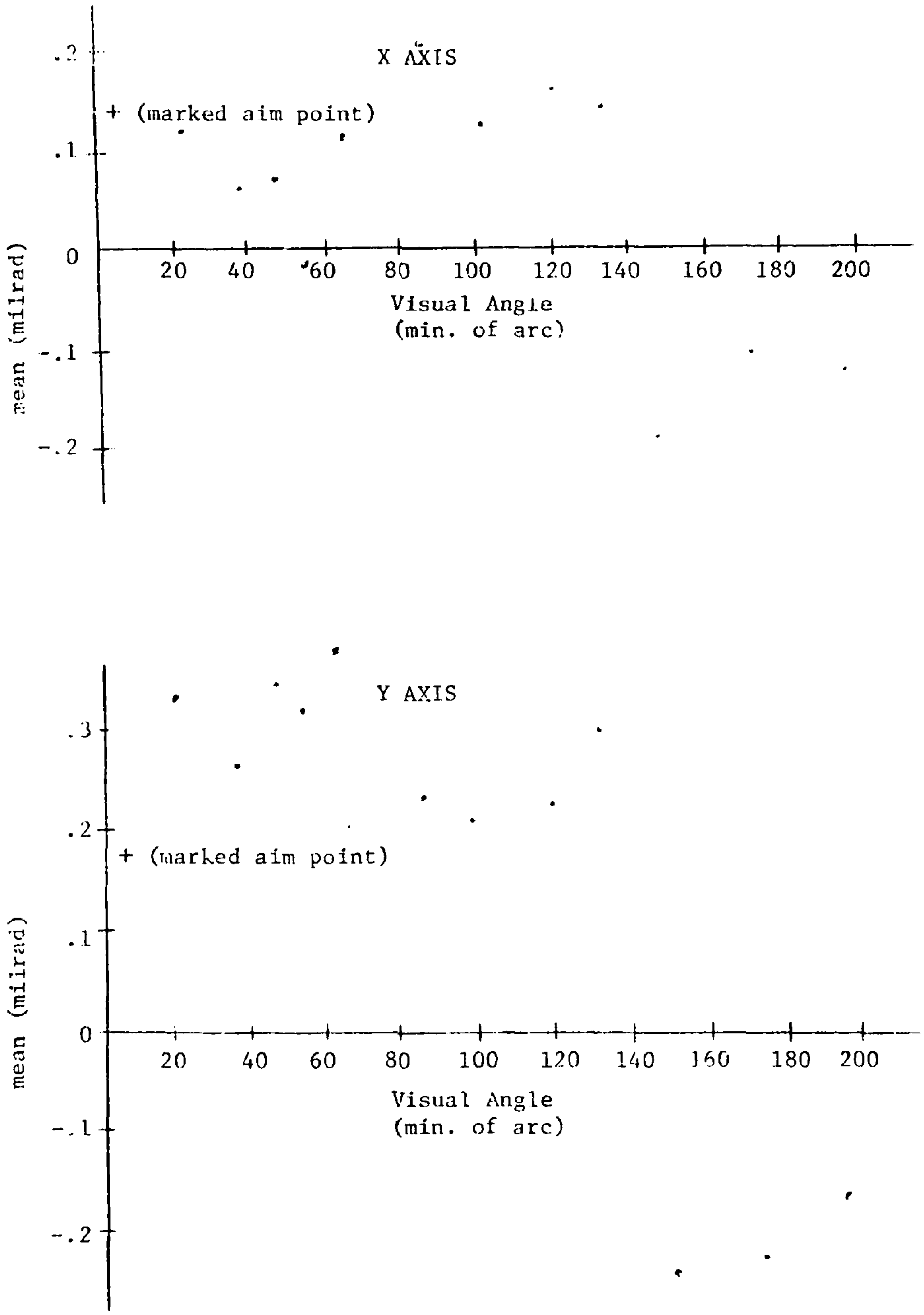
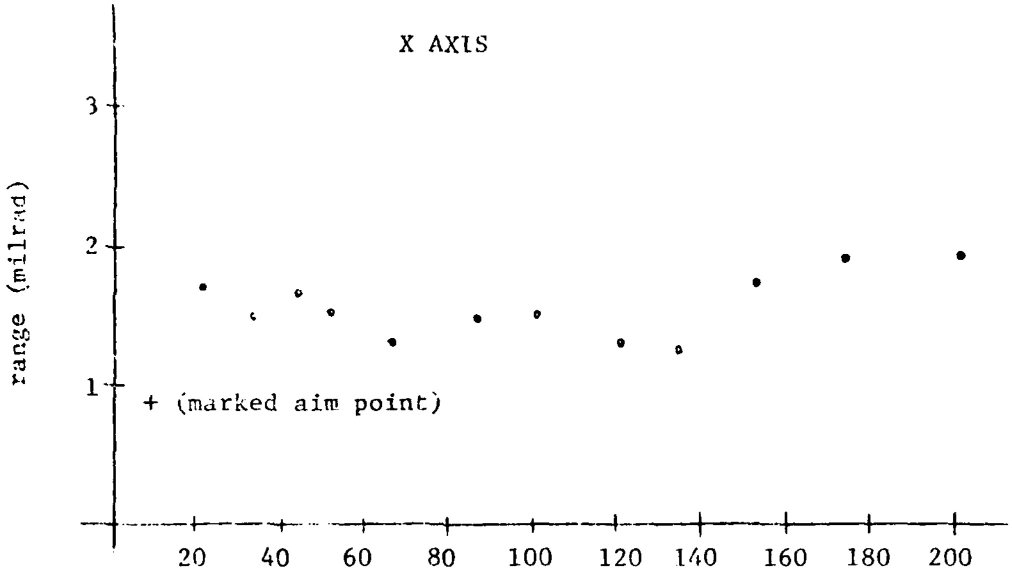


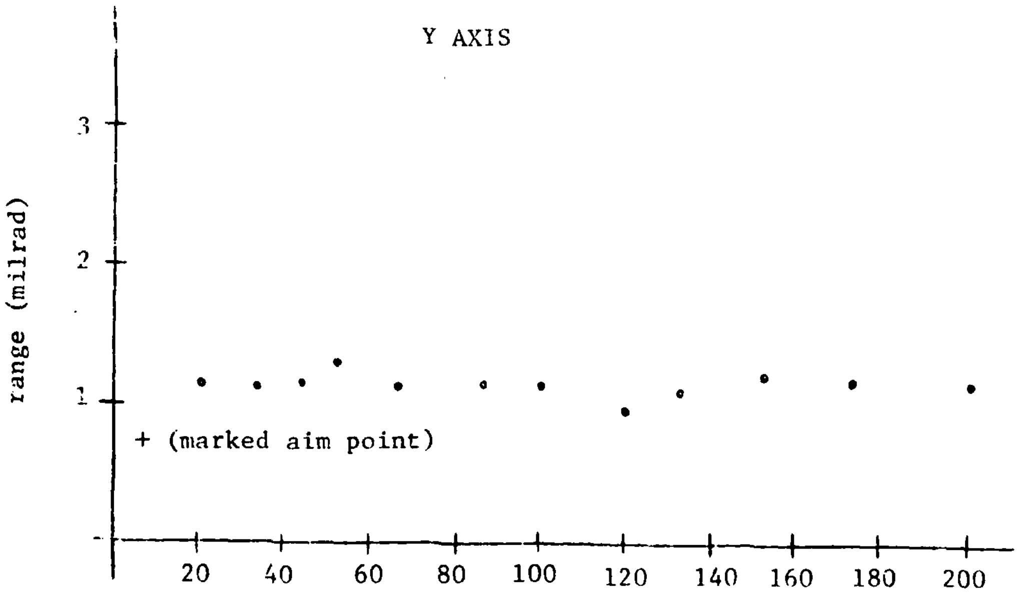
Figure 4-5. Mean Error



significant regression of first 9 points at 5%

Visual Angle (min. of arc)

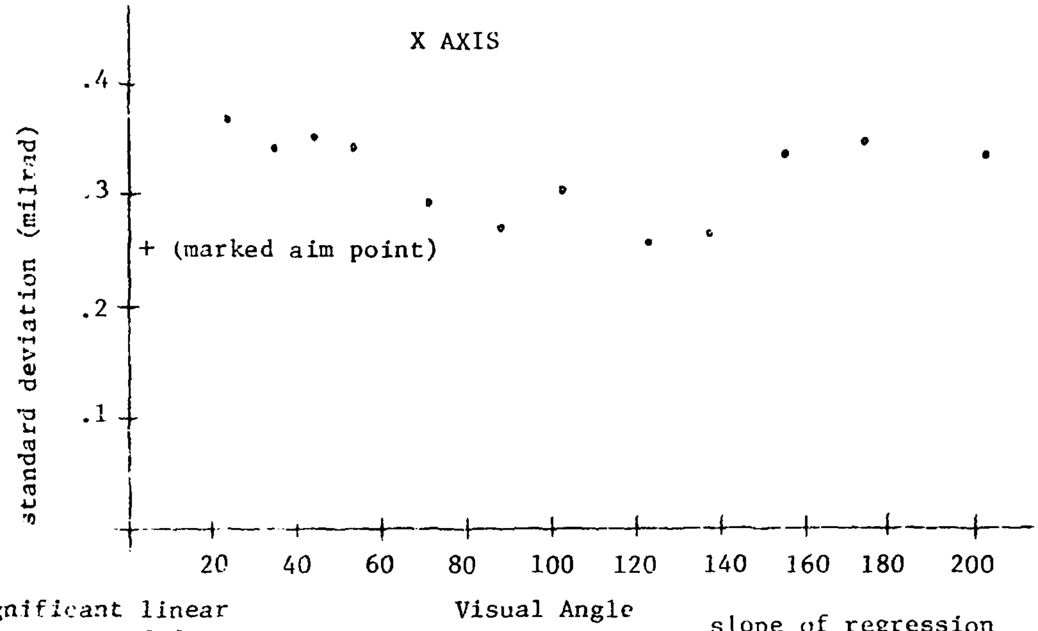
slope of regression line -.0492



no significant regression of 5%

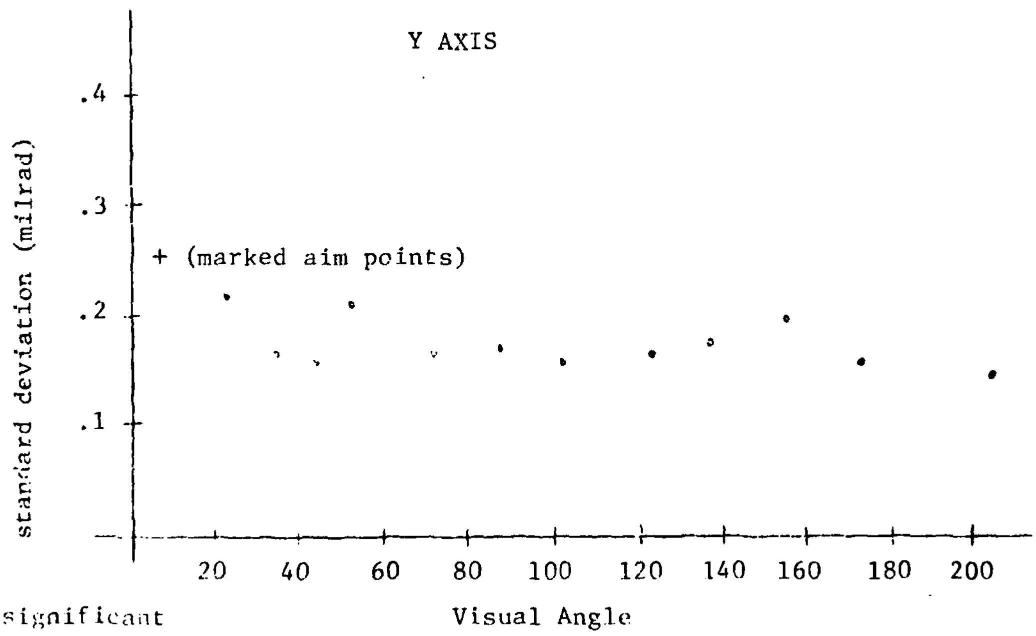
Visual Angle (min. of arc)

Figure 4-6. Range



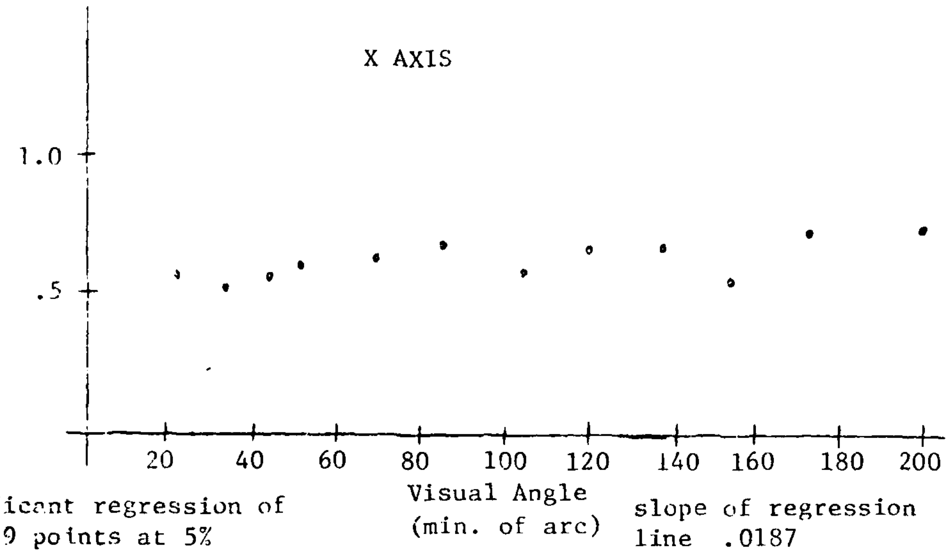
significant linear regression of first 9 points at 5%

slope of regression line -.01355



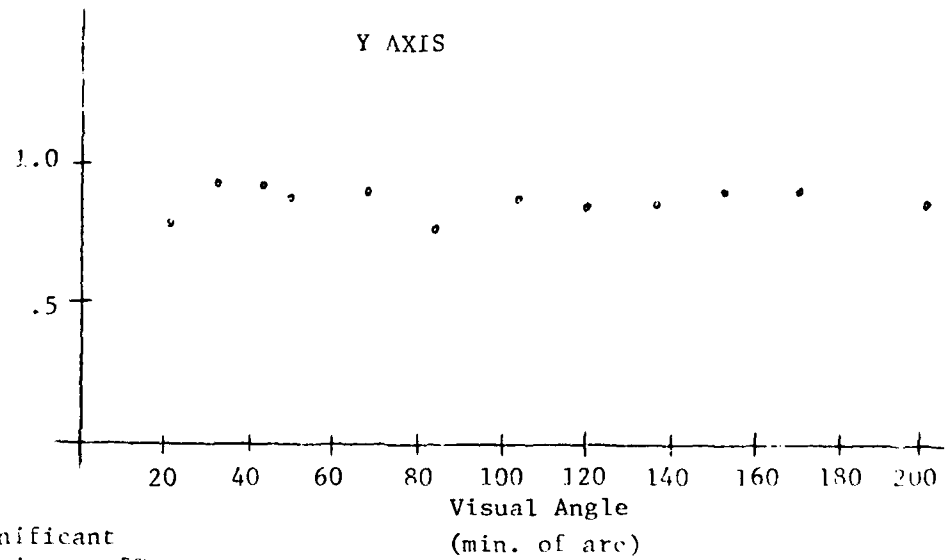
no significant regression of 5%

Figure 4-7. Standard Deviation of Error Corrected for Autocorrelation averaged for each visual angle. Figure 4-8 is a graphical representation of the results, and the computations are found in Appendix H.



significant regression of first 9 points at 5%

slope of regression line .0187



no significant regression at 5%

Figure 4-8. Autocorrelation Coefficients

CHAPTER V

CONCLUSIONS AND RECOMMENDATIONS

Conclusions

The conclusions drawn here, based on the experimental data, indicate that the distribution of error did change as a function of target visual angle. In the horizontal plane, the tendency toward a uniform distribution shifted when target visual angle was increased toward an apparent unimodal, almost spiked distribution. Although practically none of the subject distributions resembled the standard normal, it is conceivable to assume that a near normal situation could occur if a considerably increased number of data points per run was collected.

It has been shown in the literature (Bahrick, Fitts and Bragg, 1957) that the combination of tracking distributions which are not in themselves normal, often yield a combined resultant distribution which is normal. The frequency histograms derived in this research were not combined by any statistical process, thereby, preserving the individual empirical error distributions. It was felt that an examination of these distributions would give a more meaningful comparison of tracking performance on large targets.

In evaluating these error distributions, the following results were obtained. First, the standard deviation of error indicated a decreasing trend from 21.48 to 137.52 minutes of arc; at this point a large increase occurred. Here it should be noted that an actual change in target distance took place. Despite the precautions taken to ensure that conditions remained identical after the change in the tracking station, the results could reflect an alteration in experimental conditions, rather than a real change in standard deviation. Therefore, there is some doubt associated with the last three visual angles investigated. A linear regression analysis of the first nine points showed a significant, but slight, negative slope.

To further investigate the results, the mean error was calculated and plotted. The seemingly random pattern of points yielded no usable information beyond shedding more doubt about the accuracy of the last three data points.

The range of observations was the next tool of investigation. A plot of range magnitude vs. visual angle displayed a slight downward trend from 21.48 to 137.52 minutes of arc; again the last three points showed a marked difference. A regression line fitted to the first nine observations displayed the significance, although slight, of the negative slope.

The time series autocorrelation model was the final attempt at analysis. The results obtained from this model yielded a slight but statistically significant decrease in standard deviation corrected for autocorrelation as visual angle increased. Conversely, autocorrelation coefficients showed a slight but significant increase as visual angle increased. This behavior was consistent with the tendency for the error distribution to become spiked as the visual angle increased. This can be interpreted as a tendency for the tracker to make fewer corrective motions as target size increases.

In the vertical plane, the expected results were achieved. Since the course was fairly flat, little correction was made in this plane. Throughout all the frequency histograms, a large concentration of points remained around the perceived target center. This remained constant among the range of visual angles and was verified by the lack of significance, at 5 percent, of the regression lines fitted through the plots for the standard deviation of error, standard deviation corrected for autocorrelation, the range and autocorrelation coefficients.

It has been demonstrated that although the trend is statistically significant, the decrease in standard deviation as a function of visual angle is slight. In general, for practical purposes, it appears that the subjects were able to track center of mass of the circular target with very nearly the same "radial error" no matter what the apparent target size. In addition, a comparison between the standard error developed in the concurrent study on learning curves and the error obtained in this study showed marked similarity. In the concurrent study, using the same conditions and subjects, a trained subject tracked the marked center of the target with a standard deviation of error about that point of .2667 milliradians. In this study, the standard deviation of error about the smallest target visual angle was .4195 milliradians.

This indicates a substantial, 57 percent, increase in standard deviation of error when a marked aim point is not used. For practical purposes this increase is approximately constant for target sizes ranging from 20 to 200 minutes of arc. The same type of increases are present using the sample range and the standard deviation adjusted for autocorrelation. There was not a significant difference in mean tracking error of targets with marked and unmarked aim points.

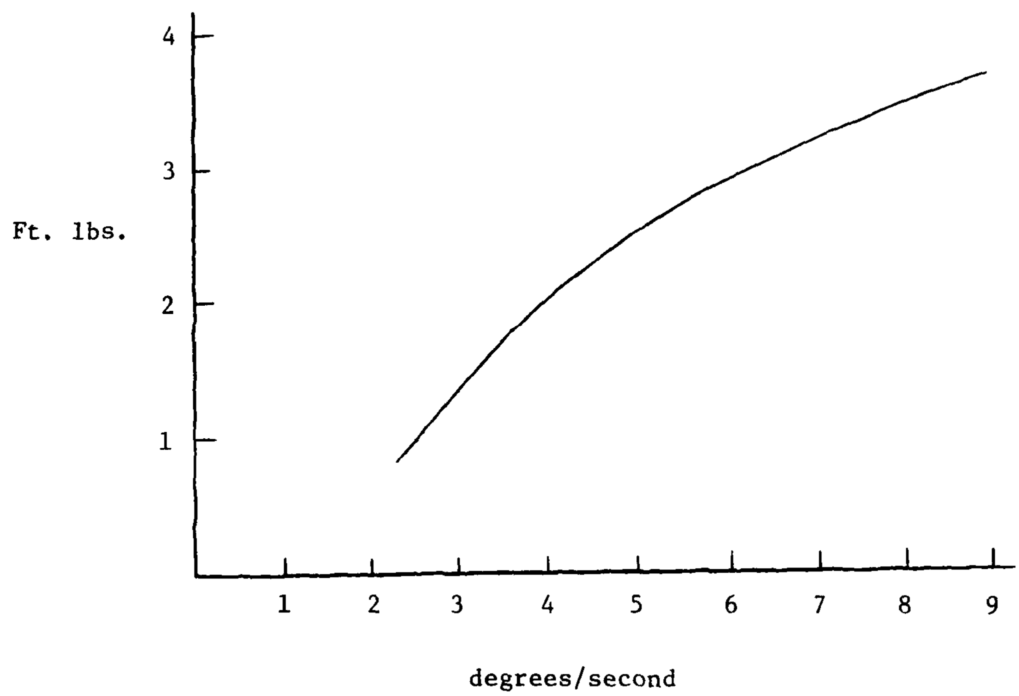
Recommendations

It seems apparent that more than 50 data points per subject trial might be desirable in order to determine a more precise distribution of error. I would recommend that in future research a minimum of 100 points per trial be collected. This, however, would require a much larger experimentation area.

It is also important to recognize that only one range should be used in future experiments. Since 200 meters was the maximum range course available for this study, it had to suffice. I would recommend at least a 400 meter range with varying target sizes. Again, a clear experimentation area of this magnitude is difficult to obtain.

It should also be noted that in this study the standard deviation of error was corrected for the autocorrelation effect. Other studies, especially where the sampling rate is other than 4 f.p.s., can not and should not be compared to this research unless their error deviations are also ammended by an autoregressive process. It is recognized that the AR(1) model used here might not have been the best statistically even though the exponential decay is evident. A further study, using a Box-Jenkins procedure, is recommended to determine the most representative model to statistically mimic the manual trucking task.

APPENDIX A



Tripod Damping Characteristics

Horizontal Plane

APPENDIX B

Subject Instructions

1. Assume a comfortable and stable sitting position.
2. Relax.
3. Keep your eye in relatively the same position over the eye piece.
4. Attempt to keep the cross hairs in the center of the target.
5. As the target moves, establish a tracking rate by applying smooth horizontal and vertical corrections to the handle on the traversing unit.
6. Breathe normally while tracking.
7. Attempt to track the center of mass of the target at all times. The white cross hair on the target at the beginning of each run will point it out, but will be removed prior to initiation of tracking.

APPENDIX C

X AXIS
Standard Deviation of Error
(Target Inches)

Subject / Condition	R	J	C	Cr	D	M	Average
1.	4.585	2.425	2.541	3.867	2.444	3.976	3.306
2.	4.731	2.513	2.199	2.217	1.718	3.849	2.871
3.	5.929	2.90	2.599	2.701	2.338	3.598	3.344
4.	4.703	2.576	3.179	2.655	2.112	3.891	3.189
5.	4.675	2.275	2.039	2.431	1.645	3.169	2.70
6.	3.895	2.853	1.906	1.633	1.897	2.529	2.452
7.	3.712	3.308	2.437	2.018	2.205	2.749	2.738
8.	2.693	2.239	2.442	2.262	2.370	3.204	2.535
9.	3.6918	1.740	2.869	2.445	2.282	2.256	2.5518
10.	2.662	1.648	1.700	1.398	1.366	1.659	1.738
11.	1.745	2.179	2.098	1.491	1.769	1.774	1.842
12.	2.056	2.282	2.021	1.946	1.458	1.470	1.872

Y AXIS
Standard Deviation of Error
(Target Inches)

Subject / Condition	R	J	C	Cr	D	M	Average
1.	2.547	2.534	1.539	2.011	2.684	3.797	2.518
2.	2.780	3.050	1.627	1.824	2.035	2.624	2.326
3.	2.975	3.851	1.550	2.013	1.482	2.609	2.470
4.	2.919	2.552	2.623	2.111	1.679	3.402	2.547
5.	3.343	2.286	1.531	2.006	1.442	2.377	2.164
6.	3.138	2.538	1.353	1.923	1.336	2.579	2.145
7.	3.016	2.483	1.859	1.671	1.643	1.334	2.001
8.	2 319	1.733	1.855	1.619	2.206	1.646	1.895
9.	3.060	1.824	1.506	1.249	1.208	2.405	1.875
10.	2.238	1.135	1.041	.676	.834	.943	1.145
11.	1.320	1.162	1.126	.465	1.235	.599	.985
12.	1.133	1.088	.979	.632	.9132	.880	.942

Average Standard Deviation Error
(Milliradians)

Condition	X	Y
1.	.4195	.3195
2.	.3645	.295
3.	.42	.313
4.	.405	.323
5.	.3429	.2748
6.	.3114	.2724
7.	.3477	.251
8.	.3219	.241
9.	.3242	.2381
10.	.404	.2908
11.	.4678	.250
12.	.474	.229

X AXIS

Mean Error
(Target Inches)

Subject / Condition	C	M	D	Cr	J	R	Average
1.	2.351	2.11	3.549	1.0217	-1.338	.8364	1.07
2.	1.037	-.1904	-1.591	1.176	-.2801	2.091	.373
3.	-.1490	-.8095	1.0329	.7838	.1428	1.549	.425
4.	.1905	-2.168	.9828	-1.981	1.884	.6113	-.08
5.	-.5079	.4376	1.882	1.655	.8396	1.313	.936
6.	-1.157	.6045	2.027	2.826	3.127	2.1398	1.59
7.	-.019	-1.396	2.63	1.165	.6756	1.839	.816
8.	-.3064	.1904	1.56	1.098	2.484	2.179	1.20
9.	.5581	-2.778	1.413	.2637	2.184	4.147	.965
10.	-.08	-2.285	1.362	-2.975	-.388	-.514	-.813
11.	-1.287	-.7619	1.058	-1.259	-.989	.3685	-.478
12.	-1.074	-.560	.4257	-1.678	-.716	.3089	-.549

Y AXIS

Mean Error
(Target Inches)

Subject / Condition	C	M	D	Cr	J	R	Average
1.	1.207	6.3	.9849	4.407	-.3894	3.395	2.65
2.	3.274	2.4036	-1.845	4.894	.7787	3.047	2.09
3.	2.948	-.5238	4.637	5.619	-.8857	4.613	2.735
4.	-1.312	2.273	2.971	2.727	3.578	3.986	2.36
5.	2.5467	1.005	5.948	1.181	2.161	5.438	3.046
6.	1.272	2.418	2.699	2.826	-1.734	2.844	1.72
7.	.7047	.3471	4.534	-.4855	-.733	4.4579	1.47
8.	1.118	3.497	4.065	1.590	-1.930	2.395	1.79
9.	1.479	3.698	2.483	1.751	1.252	2.891	2.25
10.	-1.44	-.995	-.3040	-2.148	-2.599	1.146	-1.056
11.	-2.6077	-2.298	-.846	.9206	-2.81	1.523	-1.02
12.	-1.032	-.7216	-.4033	.30158	-3.295	1.045	-.680

Average Mean Error
(Milliradians)

Condition	X	Y
1.	.135	.336
2.	.0473	.265
3.	.054	.347
4.	-.010	.299
5.	.118	.386
6.	.201	.218
7.	.103	.186
8.	.152	.227
9.	.122	.285
10.	-.206	-.268
11.	-.121	-.259
12.	-.124	-.172

APPENDIX D

X AXIS
Range of Errors
(Target Inches)

Subject / Condition	D	C	Cr	R	J	M	Average
1.	8.381	9.142	16.0	20.191	9.52	16.762	13.33
2.	7.997	8.759	9.143	16.762	11.428	14.095	11.36
3.	9.136	10.282	10.285	20.572	10.282	16.345	12.817
4.	10.285	10.66	9.143	18.667	10.667	14.857	12.378
5.	6.857	8.0	10.666	18.286	9.14	11.044	10.66
6.	7.99	8.762	6.857	14.852	10.352	11.43	10.04
7.	8.0	10.66	10.66	17.032	15.612	9.143	11.85
8.	8.0	8.762	8.857	11.429	9.905	12.571	9.93
9,	9.143	9.523	10.282	13.715	5.714	9.524	9.65
10.	5.33	6.857	6.286	12.191	5.314	5.905	6.98
11.	6.667	7.238	6.666	7.709	9.333	7.239	7.47
12.	6.54	8.571	7.235	6.852	9.52	6.095	7.46

Y AXIS

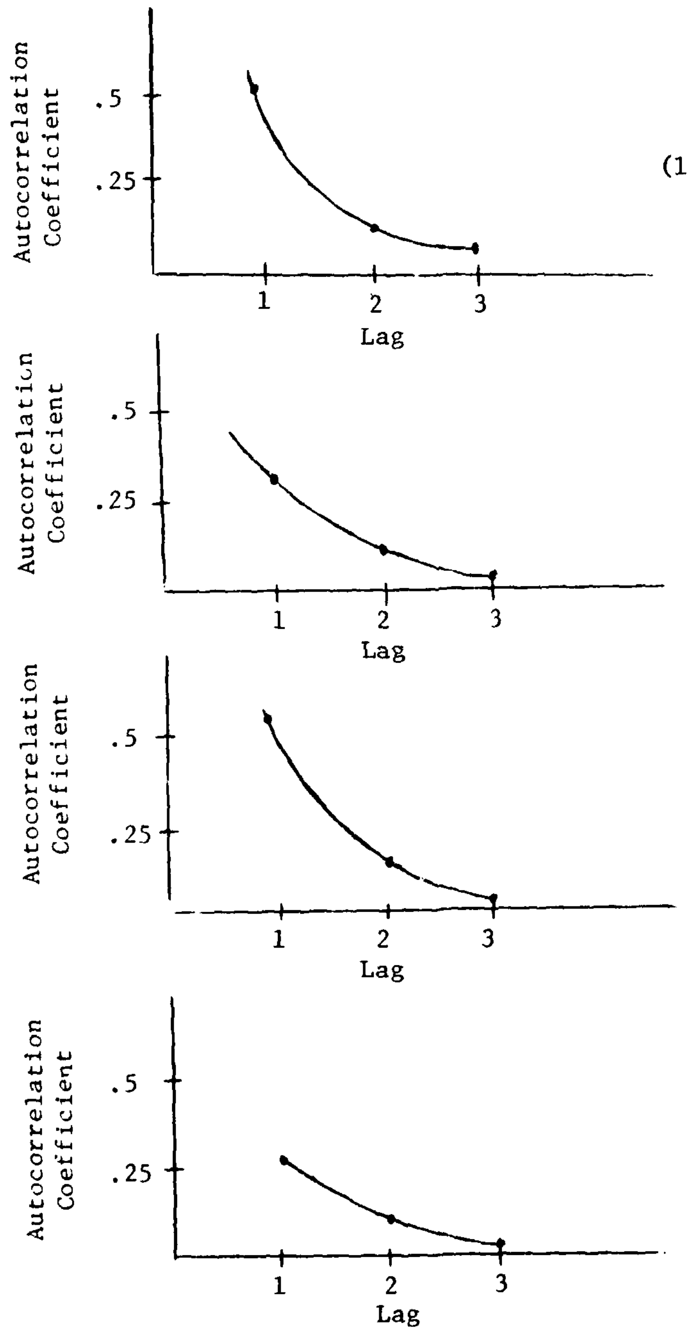
Range of Errors
(Target Inches)

Subject / Condition	D	C	Cr	R	J	M	Average
1.	11.048	6.657	7.619	11.81	10.285	15.238	10.476
2.	8	5.714	7.238	12.191	11.047	9.905	9.016
3.	9.143	7.238	8	10.286	11.809	9.142	9.270
4.	6.476	11.429	10.666	13.714	9.143	12.191	10.603
5.	9.143	6.857	6.095	11.989	9.875	8	8.660
6.	6.476	5.714	6.857	14.477	10.286	9.905	8.952
7.	8	7.238	6.095	14.857	11.047	4.95	8.698
8.	8.381	6.858	7.288	9.524	6.095	6.476	7.429
9.	5.333	6.095	5.333	14.477	9.143	8	8.064
10.	2.857	4.881	2.751	10.095	4.571	3.428	4.682
11.	5.143	4.19	2.095	6.045	4.571	4.571	4.444
12.	4.19	4.381	2.476	5.333	5.143	3.238	4.127

Average Range Error
(Milliradians)

Condition	X	Y
1.	1.693	1.1305
2.	1.443	1.145
3.	1.628	1.177
4.	1.571	1.347
5.	1.354	1.0998
6.	1.275	1.137
7.	1.505	1.105
8.	1.261	.944
9.	1.226	1.024
10.	1.773	1.189
11.	1.897	1.129
12.	1.895	1.048

APPENDIX E



(1 Unit = .25 seconds)

Sample Decay Lag 1 to Lag 3
4 Runs

APPENDIX F

Explanation of the AR(1) Model

The autoregressive process is defined to be the dependency of a current observation (x) on previous observations, $x_{t-1}, x_{t-2}, \ldots, x_{t-n}$, of the same time series with p unknown parameters. These are several autoregressive (AR) models, each suited to fit the unique dependency of the "regressed" observations of the time series data. This study used the first order model AR(1) which is detailed below.

The variance of the AR(1) process is

$$\gamma_k = \phi_1^k \frac{\sigma_\varepsilon^2}{1 - \phi_1^2} \qquad k = 0,1,\ldots$$

$$\sigma^2 = \frac{\gamma_k(1 - \phi_1^2)}{\phi_1^k}$$

For Lag 1, k = t-1 $\therefore$ k = 0

γ_0 = Unadjusted variance of the data

σ_ε^2 = Variance free from autocorrelation at Lag 1

$\phi_1^0 = 1$

ϕ_1 = Least square estimator of autoregressive parameter

$\phi = (Z'Z)^{-1} Z'X$

$$Z'Z \begin{bmatrix} N-1 & \sum_{t=2}^{N-1} X_i \\ \sum_{t=2}^{N-1} X_i & \sum_{t=2}^{N-1} X_i \end{bmatrix} \qquad Z'X \begin{bmatrix} \sum_{t=2}^{N} X_t \\ \sum_{t=2}^{N} X_t \; X_{t-1} \end{bmatrix}$$

APPENDIX G

X AXIS

Standard Deviation of Error Corrected for Autocorrelation
(Target Inches)

Subject / Condition	D	M	J	R	Cr	C	Average
1.	1.9429	3.4284	2.1018	4.1913	3.0935	2.3842	2.8570
2.	1.7528	2.989	2.2131	4.4102	2.0669	2.0149	2.5748
3.	1.5154	2.7873	2.2965	5.2193	1.8535	2.5257	2.6996
4.	1.7308	2.7625	2.2041	4.6224	2.1120	2.4579	2.6483
5.	1.3242	2.6121	1.7727	4.4204	1.8485	1.6655	2.2739
6.	1.4918	1.9854	1.9146	3.6951	1.5448	1.7765	2.0680
7.	1.7593	2.2349	2.6636	3.4008	1.8730	2.2248	2.3594
8.	1.3400	2.2711	1.9185	2.3465	1.8258	2.4156	2.0196
9.	1.1059	2.016	1.343	2.9911	1.7757	2.7008	1.9885
10.	.8870	1.1902	1.0822	2.6884	.6697	1.4060	1.3156
11.	1.1726	1.1309	1.7609	1.5641	.9097	1.6120	1.3584
12.	1.1683	.9181	1.3386	1.5594	.9668	1.8444	1.2993

Y AXIS

Standard Deviation of Error Corrected for Autocorrelation
(Target Inches)

Subject / Condition	D	M	J	R	Cr	C	Average
1.	2.1985	2.4736	1.7388	1.0463	1.2185	1.2929	1.6614
2.	1.1184	1.3028	1.1198	1.9764	1.3411	1.0848	1.3238
3.	1.2780	1.3352	.9805	1.5803	1.0198	1.2745	1.2447
4.	.9606	2.2859	1.4830	1.9896	1.3509	1.8465	1.6528
5.	1.2646	1.3789	.9474	1.9710	1.1845	1.1410	1.3146
6.	1.2765	1.1248	2.8181	1.8169	1.2034	1.2657	1.3374
7.	1.3124	.8062	1.1788	1.3611	.8835	1.7287	1.2118
8.	1.1955	1.1222	.9273	1.6088	1.1079	1.5010	1.2448
9.	.7369	1.2328	1.2409	2.4920	.8370	1.4445	1.3309
10.	.4339	.5809	.5623	1.5777	.3180	.5626	.6725
11.	.7341	.3403	.4606	.9196	.3396	.8674	.6103
12.	.5633	.4540	.5462	.8613	.3604	.5335	.5531

Average Standard Deviation of Error
Corrected for Autocorrelation
(milliradians)

Condition	X	Y
1.	.3628	.2110
2.	.3270	.1681
3.	.3429	.1581
4.	.3363	.2099
5.	.2888	.1670
6.	.2626	.1699
7.	.2996	.1581
8.	.2565	.1581
9.	.2525	.1690
10.	.3342	.1708
11.	.3450	.1550
12.	.3300	.1405

APPENDIX H

X AXIS

Autocorrelation Coefficients

Subject / Condition	C	R	M	D	J	Cr	Average
1.	.316	.402	.596	.841	.610	.609	.571
2.	.505	.444	.619	.571	.465	.471	.5125
3.	.242	.465	.638	.745	.592	.724	.570
4.	.618	.159	.764	.643	.640	.737	.593
5.	.591	.343	.562	.807	.648	.714	.610
6.	.508	.421	.667	.823	.836	.830	.680
7.	.399	.486	.660	.833	.567	.575	.576
8.	.188	.681	.682	.874	.782	.630	.639
9.	.338	.817	.765	.953	.850	.671	.732
10.	.546	.019	.838	.842	.753	.971	.522
11.	.692	.438	.751	.810	.654	.874	.702
12.	.527	.619	.781	.619	.824	.892	.710

Y AXIS

Autocorrelation Coefficients

Subject / Condition	C	R	M	D	J	Cr	Average
1.	.719	.823	.938	.599	.726	.969	.7958
2.	.938	.850	.929	.895	.920	.960	.9153
3.	.888	.937	.805	.934	.956	.978	.9158
4.	.757	.897	.828	.961	.935	.900	.8792
5.	.914	.921	.838	.966	.910	.830	.8975
6.	.652	.888	.927	.858	.855	.934	.8523
7.	.462	.884	.752	.946	.814	.815	.7793
8.	.690	.855	.947	.968	.919	.853	.8720
9.	.636	.766	.939	.936	.809	.916	.8337
10.	.928	.744	.878	.858	.979	.975	.8937
11.	.924	.850	.970	.850	.939	.905	.9063
12.	.894	.780	.914	.818	.980	.775	.8612

BIBLIOGRAPHY

1. Astrand, Per-Olof and Kaare Rodahl, Textbook of Work Physiology, New York: McGraw-Hill Book Company, 1970.

2. Bahrick, H. P., F. M. Fitts and G. E. Briggs, "Learning Curves, Arts or Artifacts," Psychological Bulletin, Vol. 54, No. 3, 1957, pp. 256-267.

3. Bilodeau, E. A., "Accuracy of Response as a Function of Target," Journal of Experimental Psychology, Vol. 47, No. 3, 1954.

4. Birmingham, H. P. and F. V. Taylor, "A Design Philosophy for Man-Machine Control Systems," Proceedings of the IRE, 42(12), 1748-1758, 1954.

5. Cornsweet, T. N., Determination of the Stimuli for Involuntary Drifts and Saccadic Eye Movements," Journal of the Optical Society of America, 1956, 46, pp. 987-993.

6. Crow, Davis, Maxfield, Statistical Manual, New York: Dover Publication Company, 1960.

7. DeGreen, Kenyon B., ed., Systems Psychology, New York: McGraw-Hill Book Company, 1970.

8. Dodwell, Peter C., Visual Pattern Recognition, New York: Holt, Rinehart and Winston, Inc., 1970.

9. Fitts, P. M., W. F. Bennett and H. P. Bahrick, "Application of Autocorrelation and Cross-Correlation Analysis to the Study of Tracking Behavior," Symposium on Air Force Human Engineering Personnel, and Training Research, November 14-16, 1955, pp. 125-141.

10. Hill, F. I., "Potential Research Topics for Support of Evaluation of Operational Tests," Presented to Evaluation Division of U.S. Army Operational Testing and Evaluation Agency, May 3, 1977.

11. "Human Tracking Performance Analysis of LDWSS Phase 1 Field Test Data (U)," Systems Performance & Concepts Directorate, Human Engineering Laboratory, Aberdeen Proving Ground, Aberdeen, Maryland, 1977.

12. Hunt, D. P., "The Effects of Curvilinear and Discrete Transformations of Error Information on Human Tracking Performance," Technical Documentary Report No. AMRL-TDR-63-137.

13. Laskin, Robert A., "Effects of Visual Acuity on Target Acquisition (U)," Paper presented at MORS, 37th Symposium, June, 1976, pp. 112-122.

14. Lawson, R. W., "Blinking: Its Role in Physical Measurement Nature," London, 1948, pp. 161, 154-157.

15. McCormick, Ernest J., Human Factors Engineering, New York: McGraw-Hill Book Company, 1970.

16. McRuer, D. T. and E. S. Krendel, Dynamic Response of Human Operators, Wright-Patterson Air Force Base, Ohio: Wright Air Development Division, T.R. 56-524, October, 1957.

17. Menty, Richard A. and John W. Senders, eds., Eye Movement and Psychological Processes, Hillsdale, N.J.: Lawrence Erlbaum Associates, 1976.

18. Montgomery, D. C. and L. A. Johnson, Forecasting and Time Series Analysis, New York: McGraw-Hill Book Company, 1976.

19. Overington, Ian, Vision and Acquisition, London: Pentech Press, 1976.

20. Ratliff, F. and L. A. Riggs,"Involuntary Motion of the Eye During Monocular Fixation," Journal of Experimental Psychology, 150, 40, pp. 154-157.

21. Senders, J. W., "The Human Operator as Monitor and Controller of Multi-degrees of Freedom Systems," Transactions of the Professional Group on Human Factors in Electronics, IEEE, HFE 5, 1, September, 1974.

22. Senders, J. W. and M. Cruzen, "Tracking Performance in Combined Compensatory and Oursuit Tasks," WADC Tr. 52-39, U.S. Air Force, 1952.

23. Sheridan, Thomas and William Ferrell, Man-Machine Systems, Cambridge, Mass.: MIT Press, 1974.

24. Van Cott, H. P. and R. G. Kinkade, Human Engineering Guide to Equipment Design, Washington, D.C.: American Institute for Research, 1972.

25. Wierwille, W., "Improvement of Human Operator's Tracking Performance by Means of Optimum Filtering and Prediction," IEEE Transactions on Human Factors in Electronics, 1964, 5, (1).

26. Wokovitch, J., "A Simple Test for Optimality," IEEE Transactions on Human Factors in Electronics, HFE 8, No. 4, 1967.